AN INTERFACE BETWEEN THE SCANIVALVE PRESSURE ACQUISITION DEVICE AND THE ASR-33 TELETYPEWRITER

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THESIS

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ABSTRACT

A logic interface was designed and fabricated for use between an existing 48-tube pressure multiplexing "Scanivalve" and an ASR-33 Teletypewriter set. The teletype has a punched paper output option, thus allowing rapid data reduction of the digitized data to dimensionless pressure coefficient form utilizing existing computer facilities such as the IBM-360/67, Wang-700, etc. The purpose of the research studies was to upgrade the data acquisition facilities and procedures employed in wind-tunnel experimentation in the Department of Aeronautics. Additionally, this work forms a portion of the overall data acquisition problem including the data logging on the wind-tunnel three-component balance.

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I. INTRODUCTION

The ultimate objective in the area of instrumentation, data acquisition, and data reduction/processing is to provide the scientist or engineer with effective tools with which to economically generate or validate sound analytical hypothesis at the laboratory level. A corollary to this objective in the academic field, as indicated in Ref. 1, is the enhancement of the student's learning process by reducing or eliminating the requirement for manual data collection and processing. The transition from manual to automatic data acquisition/processing can thus facilitate improved scientist/student productivity by economizing the time and effort devoted to the tedious and mundane numerical manipulations while maximizing analytical analysis pursuits. Realization of this objective in the laboratory facilities of the Aeronautical Department of the Naval Postgraduate School necessitates significant improvement and modification of existing equipment. There does exist,however, in stock the basic components with which to implement an effective automatic data acquisition and processing system. Hence the real problem is transfixed from one of economics and fiscal considerations to one of amalgamating and integrating existing elements into a coordinated system.

The design and development parameters of an integrated data acquisition/processing system are established through performance analysis and value judgments of available equipment

and data rate/condition requirements. The factors considered in performance analysis of equipment and signal conditioning are rather straight forward and generally well documented in associated operating manuals. Further, in the fixed base laboratory facility, the preponderance of data input is generally of an analog nature requiring minimal signal conditioning when processed to the read-out stage. Under this condition, time variation of the input data is the paramount consideration aleviated through appropriate incorporation of sample-and-hold devices. If however, the acquired raw data is to be processed through a digital computer, further signal processing must be undertaken to digitize the analog signal and shape the resulting electrical impulse train into a serial or parallel form compatible with existing digital computer facilities. The problem of processing time-varying analog signals utilizing the SAI-42 Correlation and Probability Analyzer and the IBM-360-67 digital computer has been addressed in Ref. 2.

Data acquisition rate is a design parameter which may be qualitatively trisected into the following categories (relative to a four digit-plus sign number):

slow rate......recorded at sampling speeds of up to one number per second;

medium rate....recorded at speeds from one to one hundred numbers per second;

fast rate......recorded at speeds above 100 numbers per second.

The final data acquisition/reduction system design is highly

dependent in the area of economics and complexity upon the establishment of system data rate. As a general rule the relationship between system cost and acquisition rate is exponential. This stringent limitation has been somewhat relaxed with the advent of the low cost mini-computer; however, the high cost of peripheral equipment remains.

Presently an immediate need exists for data handling at a slow rate for laboratory experiments in the Department of Aeronautics. As indicated in Ref. 1, an initial need exists in wind-tunnel data acquisition wherein balance force and moment and model pressure distribution indications are to be processed at a rate of ten characters per second. Thus it is the purpose of this thesis to address the problem of automatic wind-tunnel model pressure distribution collection and processing with the view that with minor modification the system concept may be directly applicable to acquisition and processing of steady analog signals from other laboratory instrumentation sources.

II. NATURE OF THE PROBLEM

The general data acquisition system has three stages, as noted in Ref. 3;

1. The input stage, which consists of appropriate transducers and signal conditioning circuits (amplifiers, filters, etc.).
2. A signal conversion stage, which converts the input signal, an analog voltage, to a sequence of voltage pulses representing a digital form. The conversion to digital form with existing equipment is made by transforming the voltage to frequency which in turn may be used to drive electronic counting circuits; i.e. the conversion is essentially a frequency-modulation process.
3. An output stage, which takes the digital signal and expresses it in printed form on a high speed printer sheet, plots the data on graph paper, punches the data on cards, or stores the data on magnetic or punch-paper tape. The output stage must include suitable coupling circuits to express the digital signal in a form for driving the enumerated output modes.

A. DESCRIPTION OF INPUT DEVICES

1. Scanivalve Model 48J4-1200

The 48J4 series Scanivalve is a scanning type pressure sampling valve for measuring multiple pressures. The Scanivalve

makes one integral pressure transducer and its zeroing circuit do the work of 48 transducers and 48 zero circuits; i.e. multiplexing in the physical, pressure domain. The Scanivalve consists of four major subcomponents exclusive of the pressure transducer which is selectable depending upon the pressure range, sensitivity, and dynamic characteristics desired and the heater base. These subcomponents are: (1) the drive unit (manual, solenoid, or motor), (2) the transmitter (BCD, DCML, Standard Tube Mark (STM), or Oscillograph Tube Marker OTM)), (3) the valve unit, and (4) the pneumatic connector unit. The Scanivalve subassembly combination, previously purchased by the Department of Aeronautics consisted of the J4 valve unit, one inch tubulation extended pneumatic connector, solenoid drive unit, and STM/OTM transmitter.

The Scanivalve system operates by sequentially connecting the pressure transducer to various pressure ports via a radial hole in the rotor which terminates at the collector hole. As the rotor rotates, this collector hole passes under the pressure inlet ports of the stator. Referring to the cut away drawing Fig. 1, the rotor is seen to be rigidly supported by a thrust bearing enabling the system to operate up to pressure inputs of 500 psid. The stator is elastically connected to the block in a manner which allows the stator to follow the surface of the rotor. Thus the pneumatic forces (pressure x area) at each pressure inlet port which tend to force the rotor away from the stator are withstood by the ball thrust bearing. Further, because of the relatively

insignificant volumetric change created by inlet pressure venting to the collector, transducer stabilization time requirements are minimal and for most applications may be neglected [Ref. 4] . The complete operating parameters for the 48J4-1200 Scanivalve are presented in Table I.

The Scanivalve is sequentially advanced from the "home" position (port number 48) via the scanivalve control unit,which will be discussed later, to the solenoid drive unit. The position transmitter generates a train of square waves with each particular train corresponding to a specific valve position or tubulation.

2. Solenoid Controller CTLR S2-S6

The Solenoid Controller is designed to increase the stepping speed of the Ledex solenoid driven Scanivalve [Ref. 5]. The unit consists of a self-contained isolated power supply (for both Controller and Scanivalve), solenoid drive circuit, "homing" circuit, "home" indicator, relay and manual control. Complete specifications for the Solenoid Controller are presented in Table II.

To provide a centralized, compact automatic pressure acquisition system, the Controller was modified to facilitate mounting and activation from a standard 18 inch instrumentation rack panel. The modification consisted of transferring the power indication light from the Controller unit to the face of the instrumentation panel and wiring an additional power switch in parallel with the existing switch. These modifications are indicated in Fig. 2. Additionally, a panel

support bracket was installed, note Fig. 3, to provide adequate structural integrity.

3. Differential Pressure Transducer PM131TC $\pm$ 2.5-350

The PM131TC bi-directional differential pressure transducer is a small, lightweight instrument utilizing an unbonded, fully active strain gage (Wheatstone) bridge. Selection of this transducer for incorporation into the automatic pressure acquisition system was based upon availability, adequacy, and adaptability to the 48J4-1200 Scanivalve. For most applications of a wind-tunnel nature in the Department of Aeronautics, the pressure range of $\pm$ 2.5 psid of this transducer is adequate. The maximum velocity of the low speed wind-tunnel, for example, results in a maximum dynamic pressure (q) of 60 psf which equates to a pressure coefficient range of $\pm$ 2.0. Additionally, the flush-diaphragm construction of the transducer permits direct exposure to the pressure media and a system response that is flat to one-fifth of the transducer's natural frequency (3500 hz). A complete list of transducer specifications is noted in Table III. and appropriate wiring diagrams are provided in Fig. 12.

B. DESCRIPTION OF DATEL DIGITAL PANEL METER MODEL DM-100

The DM-100 digital panel meter (DPM) is a small compact digital voltmeter utilizing state-of-the-art monolithic/MSI devices to facilitate analog to digital conversion and a solid-state display read-out employing Light Emitting Diodes (LED). The analog-to-digital converter input voltage range is $\pm$ 1.999 volts with a digitizer accuracy of $\pm$ 0.05% of

reading ± 1 count. The data output is in Binary Coded Decimal (BCD) format (8-4-2-1) positive logic loading. Conversion rate is 0 to 2000 conversions per second. The complete operating specifications are tabulated in Ref. 6. Additionally the wiring diagrams for incorporation of the DM-100 into the data acquisition system proposed by this thesis is provided in Ref. 7.

C. ANALOG TO ASCII CONTROL BOARD

The output of the DM-100 DATEL DPM is, as previously noted, provided in a BCD format. Since BCD format is not directly applicable to existing computer input facilities, it is necessary to convert this BCD output train to the more flexible American Standard Code for Information Interchange (ASCII). The theory and corresponding hardware for this conversion process was developed in Ref. 2 and modified as per Ref. 7 (extracts of which are included in Appendix A).

III. DEFINITION OF DESIGN

The availability of the parallel BCD output from the DATEL DM-100 DPM, BCD to ASCII conversion, and direct ASCII input and output data flow through the ASR-33 to the Wang 700 calculator interface and/or the IBM 360/67 computer facilitates the design of an effective data processing system. Integration of these components with and development of a flexible data acquisition element posed several problems.

The initial consideration in incorporation of the commercially produced Scanivalve/pressure transducer combination into the data acquisition system was the development of adequate controlling circuits. This control network must have the capability of:

1. insuring the identification of the scanivalve pressure port being sampled;
2. variable speed;
3. automatic and manual operation;
4. synchronization with peripheral units.

Various schemes facilitating pressure port identification were available. The most expedient approach consisted of decoding the STM/OTM identification code train generated by the Scanivalve transmitter unit. Although this solution provided positive identification of the port being sampled, a major complication was encountered. There existed the requirement for an OTM decoding circuit. Since the OTM output was specifically designed for oscillagram presentation, incorporation

would have required the conversion of the OTM to BCD to provide a readily available visual display.

Another feasible solution evolved from the positive action of the Scanivalve/Solenoid Controller. Given a 5v positive square wave, minimum of 5 milliseconds pulse width, generated by the manual stepping switch on the front face of the Solenoid Controller, the Scanivalve advances one and only one pressure port step. Likewise, a similar pulse is generated by the manual "home" switch on the Solenoid Controller which results in the Scanivalve cycling to pressure port 48 or the zero port. Thus, considering the positive action of the Scanivalve to an input step pulse and the definiteness of the "homing" pulse, an effective and efficient identification scheme can be provided by simply counting the input step pulses and incorporating appropriate visual displays.

Variable speed in the Scanivalve control circuit is essential to insure accurate yet rapid data acquisition and processing. As has been indicated, one of the primary advantages derived from utilization of the Scanivalve/pressure transducer combination as a pressure data collection instrument is the infinitesmal volumetric change encountered when sampling numerous pressure ports. The consequence of this operational aspect is that the time required to insure stable pressure measurements upon switching the pressure port being sampled is minimal. Since there is, however, a finite pressure change between each pressure port, there exists a time delay between pressure application to the transducer and digital voltmeter signal stabilization.

Another desirable feature of the Scanivalve control circuit is the selectability of automatic or manual operation. In the automatic mode of operation, after installation of the wind-tunnel model, connection of appropriate electrical and pressure connections, and determination of calibration factors, the system should be capable of sequentially selecting pressure ports and providing corresponding coefficients of pressure in a "hands off" manner. Conversely, there will occur instances in which these aspects of data acquisition may of necessity be obtained in a manual mode with varying degrees of manual operation. The two primary degrees of manual operation are:

1. manual selection of pressure port with automatic data reduction, and
2. manual selection with manual data reduction.

The manual operation requirement thus dictates the necessity for incorporation of manual control circuits for the Scanivalve and a visual digital display of the pressure transducer output.

Finally and most significantly, there exists the requirement for system synchronization. In a Scanivalve pressure acquisition and data reduction system, as alluded to previously, there is the necessity to insure and design for pressure and digital representation stabilization. After adequate signal stabilization has been achieved, the system should generate an internal command signal to:

1. hold the signal;

2. initiate BCD to ASCII conversion (when utilizing the IBM-360 or Wang 700 digital computers for data reduction via the ASR-33 TTY);
3. pause to allow time for data reduction if the system is operating in a real time mode (if data is to be stored on ASR-33 TTY punch paper tape, step 3 may be deleted);
4. advance the Scanivalve to the next sequential pressure port and repeat the data acquisition cycle.

Finally, after all pressure ports have been sampled and the data acquisition cycles completed, the system should generate a command signal to return to the "home" position of the Scanivalve and hold, awaiting, for example, change in model attitude or wind-tunnel q, before reactivation of the system.

IV. DISCUSSION OF DESIGN

The finalized pressure data acquisition/processing system, based upon parameters established in the Definition of Design (Sec. III), consists of the following components:

1. Synchronization/timing unit,
2. Comparator circuit,
3. Automatic Scanivalve advance,
4. Manual Scanivalve advance,
5. Automatic home circuit,
6. Manual home circuit,
7. Pressure sensing system,
8. Signal conditioner,
9. Scanivalve,
10. Solenoid Controller,
11. Analog-to-digital converter circuit,
12. ASR-33 TTY,
13. BCD-to-ASCII converter and BCD-to-MONROE machine language converter,
14. Calculator/computer facility.

The synchronization/timing unit, discussed in Sec. V, utilizes a monolithic TTL integrated circuit one-shot multivibrator with external timing components to generate a 60 Hz or 110 Hz variable pulse width square wave. The buffered output from the multivibrator is utilized for synchronization of external components, ASR-33 TTY (110 Hz) or MONROE 1666 (60 Hz), and internal timing. This internal timing function

specifically applies to the advance rate of the Scanivalve. Since pressure acquisition rate is dependent upon the calculator/computer system being utilized for data reduction, a variable advance speed is achieved by incorporating TTL 4-bit binary counters which reduce the multivibrator output by factors of 64, 128, and 256. These reductions provide Scanivalve advance rates ranging from 0.25 to 1 step per second.

The advance pulses are routed through the Automatic/Manual switch S1 (note instrument panel location Fig. 2) which provides the implied source advance pulses for the Comparator Circuit (Sec. VI). In the manual mode, discussed in Sec. VIII, the Scanivalve advance pulse is generated by a one-shot multivibrator activated by the Manual Advance push button switch S4 (note panel location Fig. 2). In the automatic mode, the input to the Automatic/Manual switch comes from the speed selector switch (low, medium, or high speed) S5.

The Comparator circuit, applicable primarily in the automatic mode, receives its input from the thumb-wheel selector switch (note location Fig. 2) which contains the numerical value (2 digits) of the maximum number of pressure ports to be sequentially sampled and from the decade counters of the visual position display circuit (note Sec. VI for complete discussion). The outputs from these sources are routed through various inverters, NAND gates, and NOR gates to determine coincidence of the BCD characters. Total coincidence, MSD and LSD, results in activation of the Homing circuit. The system will, however, continue to advance sequentially, both

the Scanivalve and the LED visual position indicator, until coincidence has been achieved. The Scanivalve advance is achieved through the stepping pulse being applied to the base of the switching transistor which actuates the Solenoid Controller stepping circuit (note Fig. 4).

The Homing circuit, discussed in Sec. VII, provides both manual and automatic output pulses to the Solenoid Controller via the switching circuit illustrated in Fig. 4. In the automatic mode, upon determination of coincidence of the BCD outputs from the thumb-wheel selector switch and from the decade counters of the LED circuits, a one-shot multivibrator is activated generating a square wave (minimum pulse width of 5 milliseconds) which accomplishes the following:

1. Pulses the Scanivalve Home circuit;
2. Inhibits the power to the 4-bit counters to hold the system until reactivation;
3. Resets the LED's to zero.

The manual home function is provided utilizing the circuits incorporated in the automatic home circuit with the addition of the Manual Home/Reset push-button switch S6 (note location Fig. 2). The function of this switch is to manually interrupt the sequential collection and processing of pressure data prior to the planned termination of any experimental exercise. Additionally, this switch reactivates the system after a home sequence has been accomplished through the reapplication of power to the 4-bit binary counters.

Pressure data collection is accomplished through the combining of the Scanivalve multiplexing potential with a pressure transducer and signal conditioning circuit (discussed in Sec. IX). The pressure transducer, a Statham bi-stable differential pressure transducer model PM131TC $\pm$ 2.5-350, produces an analog voltage linearly proportional to the applied pressure. This signal is amplified through the variable gain Burr-Brown operational amplifier, type 3440J, and routed to the analog-to-digital converter incorporated in the DATEL Digital Panel Meter (DPM) model DM-100. With an input impedance of 351 ohms to the operational amplifier and a variable output impedance of 100-150 Kohms, a variable amplification factor, range 285-427, is provided to facilitate full-scale digital voltmeter indication while accomodating variations in transducer and digital voltmeter combinations. The DM-100 (DPM) with a range of $\pm$ 1.999 volts produces a BCD output representative of the analog input from the pressure transducer/operational amplifier combination. This digitized signal is inhibited, analogous to a sample-and-hold evolution, by the Scanivalve advance gate output. Once the inhibit pulse is present in the analog-to-digital converter, the held BCD signal is converted to ASCII for transfer to the ASR-33 TTY (note conversion process Ref. 2 and Appendix A) or routed to the MONROE 1666 interface for conversion to machine language (note Ref. 7). After transfer and conversion of the sampled BCD output, a reset gate is generated to unlock the analog-to-digital converter, enabling the processing of the analog

signal corresponding to the next sequential Scanivalve pressure port.

Through the above sequence of data acquisition and signal conditioning steps, a digitized representation of the sampled data is realized. These digitized data, upon processing through the applicable calculator/computer interface, are then in a format suitable for reduction into dimensionless coefficient form in the incorporated computer system and subsequent determination of the aerodynamic performance characteristics associated with the model pressure distribution.

V. TIMING CIRCUIT

Synchronization of the Scanivalve pressure multiplexing/ data reduction system is achieved utilizing a solid-state digital timing circuit. This digital timing circuit provides:

1. 60 Hz square wave timing gate for synchronization with the Monroe 1666 digital computer;
2. 110 Hz square wave timing gate for synchronization with the ASR-33 TTY;
3. high, medium, and low speed options to control Scanivalve sequential advance rate.

The timing circuit consists of:

1. a monostable multivibrator;
2. a NAND gate output buffer;
3. two 4-bit binary counters;
4. Manual/Automatic switch S1;
5. Internal/External timing source switch S2;
6. 60 Hz/110 Hz selectable timing gate switch S3 (note: either 60 Hz or 110 Hz timing signals may be generated at any instant with the selection dictated by the particular computer system synchronization requirement; i.e. 60 Hz for Monroe or 110 Hz for ASR-33 TTY);
7. high, medium, or low speed selectable Scanivalve stepping switch S5.

$\frac{1}{RC} = t$

$\frac{1}{(20\times10^{-6})(50\times10^{3})} = \frac{1}{1000\times10^{-3}} = \frac{1}{1000}\times10^{3}$

$(20\times10^{-6})(5\times10^{3})$

100×10^{-4}

$1000\times10^{-3} =$

0.001

10 msec

1 sec

1000

1 µf

500 Ω

20 µf

$(9\times10^{3})(1\times10^{-6})$

$(1\times10^{-6})(\cancel{909}\times10^{3})$

9×10^{-3}

$.009$

9.09×10^{-4}

$\cancel{.0909}$

5

A. MONOSTABLE MULTIVIBRATOR

The monostable multivibrator is a monolithic TTL integrated circuit, type N74121 (Signetics), which features d-c triggering from positive or gated negative-going inputs with inhibit facility [Ref. 8]. Normal operation for the N74121 is in the "one-shot" mode in which appropriate input triggers corresponding to the truth table, p. 2-112 Ref. 8 , generate a square wave output which is independent of further transitions on the inputs and are a function only of the timing components. Conversion of the N74121 from the "one-shot" mode to a continuous square wave generating multivibrator was accomplished by providing a feed back loop in which the output pulse (pin 6) is routed through an RC delay circuit to the input (pin 5) (note timing circuit logic diagram Fig. 5). This RC circuit provides both frequency and wave shaping control.

The pulse width of the output square wave is controlled by the external timing components, R_{ext} and C_{ext}, connected between pins 14 and 11, and pins 11 and 10 respectively. The N74121 incorporates an internal timing resistor which if utilized generates a 30 nanosecond pulse width. Since, however, the Scanivalve stepping solenoid requires a minimum pulse width of 5 milliseconds for activation, the following external timing components were utilized:

1. C_{ext} = 20 micro farads;
2. R_{ext} = 0-75 Kohms (variable).

This combination of external components provides a pulse width range of 0-1.5 seconds.

Since the feedback loop provides the trigger input, the variable external resistance, R_{ext}, in addition to determining the output pulse width, is utilized to establish the output frequency. Therefore, two resistors are connected to pin 11 from pin 14 through the 60 Hz/110 Hz switch S3 with the corresponding variable resistor adjusted to provide the desired output frequency.

B. OUTPUT BUFFER

To insure stable operation of the multivibrator, the output from the N74121, pin 1, is routed through a NAND gate prior to further circuit utilization to provide load isolation. The NAND gate buffer utilizes the Fairchild TTL type 9002 [Ref. 9]. With the input from the N74121 into pins 12 and 13 of the 9002, the signal is inverted to provide a stable positive square wave for external synchronization. Additionally, the N74121 output is routed to the Internal/External switch S2 from which signal source is selected and returned to pins 1 and 2 of the NAND gate where the signal is isolated and inverted prior to transfer to the 4-bit binary counters.

C. BINARY COUNTERS

The input to the binary counter circuits is a buffered 60 Hz or 110 Hz positive square wave. Since the Scanivalve advance speed is limited to a range of 0.25 to 1 step per second, to accommodate:

1. signal stabilization;
2. analog to digital conversion;

3. BCD to ASCII conversion (when ASR-33 TTY is utilized as data acquisition/computer interface;

4. data reduction/processing;

the input command and control signal must be significantly reduced. This stepping speed reduction is accomplished through the use of two 4-bit binary counters which are connected in series; i.e. the output of the first counter is utilized as the input to the second counter.

The 4-bit binary counters utilized in the Scanivalve control circuit are Fairchild type TTL/MSI 7493 which is a monolithic integrated circuit consisting of four master/slave flip-flops. The flip-flops are internally connected to provide a divide-by-two and a divide-by-eight counter. Both 7493's, however, were modified to operate as 4-bit ripple through counters to provide simultaneously, divisions of 2, 4, 8, and 16. This modification consisted of connecting the output, pin 12, to the input, pin 1 (note card I wiring diagram Fig. 6). The divide function outputs are as follows:

1. pin 12 divide-by-two;
2. pin 9 divide-by-four;
3. pin 8 divide-by-eight;
4. pin 11 divide-by-sixteen.

The output from the first 7493 is taken from pin 11 (divide-by-sixteen) and routed to the input pin 14 of a second 7493. With external connections corresponding to the first binary counter, the second counter provides the following divide functions relative to the timing clock input:

1. pin 12 divide-by-32;
2. pin 9 divide-by-64;
3. pin 8 divide-by-128;
4. pin 11 divide-by-256.

The outputs from pins 9, 8, and 11 are routed to the Scanivalve speed control switch S5 corresponding to high, medium, and low speed respectively. The speed count output pulses are then routed to the Manual/Automatic switch S1 through which they are directed to circuits to:

1. advance the Scanivalve to the next sequential pressure port, and
2. increment the LED visual display indicating the pressure port being sampled.

Complete specifications and truth tables for the 7493 are provided on p. 8-248 Ref. 9.

VI. COMPARATOR CIRCUITS

A. SCANIVALVE POSITION INDICATOR CIRCUIT

The requirement for visual verification of the Scanivalve pressure port being sampled at any instant is achieved through the use of a pre-packaged digital counting, decoding, and display circuit. The digital counting circuit consists of two decade counters, type N7490 (Signetics), which are monolithic TTL's, wired in series to provide a most-significant-digit (MSD) and a least-significant-digit (LSD) count display. The N7490 consists of four dual-rank, master flip-flops internally interconnected to provide a divide-by-two counter and a divide-by-five counter. Additionally, gated direct reset lines are provided to inhibit count inputs and return all outputs to a logic "0" or a BCD count of 9. Through variation in external pin connection, the mode of operation of the N7490 may be altered. The particular mode utilized in the Scanivalve indicator system is the BCD decade counter mode. This is achieved by connecting the binary decimal (BD) input, pin 1, to the output pin 12, of the N7490 (note: wire diagram Appendix A). In addition to the conventional "0" reset, inputs are provided to reset a BCD 9 count for nine's compliment. Thus a two significant digit count can be maintained by connecting the 9 count output, pin 11,of the first N7490 to the input, pin 14,of a second N7490.

In addition to the internal use of the BCD code generated by the decade counters, external connections are provided and

utilized in a comparater circuit to determine coincidence of signal (step count) with the output from the "thumb-wheel" selector switch. The BCD count output for each N7490 is as follows:

Count	pin 11	pin 8	pin 9	pin 12
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

(truth table for N7490 from p. 2-94, Ref. 9)

The BCD outputs from the N7490's are routed through N7475 quadruple bi-stable latches which provide temporary storage between the processing unit and the input/output or indicator unit. The quad latches are retained artificially in a high state to allow continuous data flow.

From the quad latches the BCD signal is routed to two BCD-to-seven segment decoder/drivers. The N7447 decoder/driver is a TTL monolithic device consisting of necessary logic to decode a BCD code to seven-segment readout plus selected sign. The complete circuitry and truth table for the N7447 is provided on p. 2-50 Ref. 9.

The outputs from the N7447's are sent to two LED indicators mounted on the face of the instrumentation/control panel. Thus through the BCD counters, latches, decoders and LED indicators, the position of the Scanivalve pressure sensing port is determined and displayed. A wiring diagram of the visual position display is provided in Fig. 7.

B. THUMB-WHEEL SELECTOR CIRCUITS

To provide automatic operation of the Scanivalve control circuit, two BCD thumb-wheel selector switches are incorporated and mounted on the instrumentation/control panel. The function of these switches is to provide a means of pre-selecting the maximum number of sequential Scanivalve ports to be sampled during any particular experimental evolution.

The thumb-wheel selector switches produce a negative logic BCD code corresponding to the decimal digits which are manually selected. This BCD output is converted to positive logic by utilizing monolithic, type 9016, inverters. For both 9016's, most-significant-digit (MSD) and least-significant-digit (LSD), the following outputs are generated by the thumb-wheel switches and are routed to the indicated pin inputs:

BCD Count	pin no. (9016 input)
0	1
1	3
2	5
4	9

C. COMPARATOR CIRCUIT

The outputs from the 9016's are routed to the inputs of NAND gates for comparison with the outputs of the N7490 decade counters. The NAND gates utilized are monolithic TTL type N7486. The following inputs for both MSD and LSD are provided into the N7486's:

BCD count	9016 input pin no.	7490 input pin no.	NAND output pin no.
0	1	2	3
1	4	5	6
2	9	10	8
4	12	13	11

The logic of the N7486 NAND gates is such that the output is "1" or "high" under all input conditions except when both inputs are logic high. In the case where both inputs are high, the output of the NAND gate is logic low. Hence when the logic level from the thumb-wheel selector switch for each BCD character output coincides with the corresponding BCD character output from the decade counters of the visual display circuit, the logic level of the NAND gate in the comparator circuit is low. There are however, four BCD character outputs from each decade counter and each 9016. Thus, to verify coincidence of each BCD character, MSD and LSD, after comparison of corresponding characters in the NAND gates, the outputs from the NAND gates are routed to a NOR gate. The NOR gate utilized is the monolithic TTL type N7425 which is a dual 4-input NOR gate with strobe (note truth tables and internal logic diagram p. 5-61, Ref. 8). The logic of the N7425 is such that the output for either 4-input NOR gate is low except when all four inputs are low at which time the output of the N7425 is logic high. Therefore the four outputs from each N7486, MSD NAND gate and LSD NAND gate, are routed to the inputs of the dual 4-input NOR gate where total coincidence of the BCD characters generated by the

thumb-wheel selector circuit and the decade counters is ascertained. Further, if "00" is inserted into the thumb-wheel circuit, the automatic Scanivalve advance system will not activate since this is considered a trivial exercise and the Scanivalve position is maintained at the zero port; i.e. the "homing" circuit is not activated. A logic diagram of the comparator circuit is provided in Fig. 8 while a wiring diagram of this circuit is included in Fig. 9.

VII. HOMING CIRCUITS

A. AUTOMATIC HOMING

When the Scanivalve position indicator coincides with the numerical value pre-set into the thumb-wheel selector switch, the system is designed to return to the home position and hold until further activation. This is accomplished through the utilization of a one-shot multivibrator and a flip-flop circuit.

1. One-shot Multivibrator Circuit

Upon determination of BCD character coincidence in the NOR gates, the outputs from the N7425, pin 8 for MSD and pin 6 for LSD, are routed to a NAND gate, type 9002, where the two inputs are compared. When MSD and LSD circuits indicate coincidence, the inputs to the 9002 are logic high resulting in a logic low output. This low going signal is then utilized to activate a one-shot multivibrator which in turn sets a J-K flip-flop and pulses the Scanivalve control homing circuit.

The one-shot multivibrator utilized is a Signetics monolithic TTL type N74122 which is a retriggerable monostable multivibrator with a clear function. Although an internal resistor is provided to generate a 21 nanosecond pulse width square wave output, external components C_{ext} and R_{ext} are utilized to achieve the 5 millisecond square wave pulse width requirement dictated by the Scanivalve home control circuit

(note Fig. 10). To achieve this desired pulse width the following external components are utilized:

a. C_{ext} = 50 micro farads;

b. R_{ext} = 0-75 Kohms (variable).

This combination of external components provides an output pulse width range of 0-1.2 seconds as determined by eq. 1.

$$(1) \quad t_w = 0.32 \times R_{ext} \times C_{ext} \times \left(1+\frac{0.7}{R_{ext}}\right)$$

where R_{ext} is in Kohms

C_{ext} is in pF

t_w is in nanoseconds

(note: characteristic equation of the N74122 output response p. 2-116, Ref. 9)

The positive square wave output from the N74122, pin 8, is routed to a NAND gate, type 9002, to provide system isolation for the multivibrator. By connecting input pins 12 and 13 of the 9002 together, the output, pin 13, is held logic high until the multivibrator is activated thus generating a positive square wave which transitions the output to logic low. This inverted and isolated square wave is then routed to the flip-flop circuit.

2. Flip-flop Circuit

As noted previously, the function of the flip-flop circuit is to transfer the homing pulse generated by the multivibrator to the Scanivalve control circuit and to reset and hold the Scanivalve stepping circuits. The flip-flop utilized in this circuit is the Signetics monolithic TTL,

4-bit binary counter (note p. 2-100, Ref. 9). This is essentially a substitute integrated circuit for a master/slave J-K flip-flop. The operation of the N7493 is described in Sec. IV(C). The application of the IC in a straight flip-flop mode is accomplished by utilizing the divide-by-two function. Therefore, the output of the N7493, pin 9, is maintained in a given state, high or low, until altered by the input square wave from the multivibrator. Since the 4-bit binary counter is activated by both positive going and negative going logic present in the input square wave, the divide-by-two function insures a single output transition for each square wave input.

The output from the N7493 is sent to the LSD 9016 inverter where the flip-flop output signal is isolated and inverted. When the automatic homing signal is generated, a transition from logic low to logic high is initiated by the N7493 which results in a logic low output from pin 12 of the inverter. This output results in the Scanivalve home control circuit being activated to cycle the Scanivalve to the zero port and removing the power from pin 4 of the second N7493 in the timing circuit. This latter action results in all further automatic Scanivalve advance attempts being inhibited; i.e., the Scanivalve is held at the zero port. Additionally, the output from the 9016, pin 12, is connected to pin 11 and the input inverted to provide a logic high output, pin 10, which is used to reset the LED visual indicators and associated decade counters to zero.

B. MANUAL HOMING

To inhibit the action of the Scanivalve advance control circuitry after activation in the automatic mode and prior to the automatic homing and inhibit described above, and to reactivate the automatic system, a manual homing and reset circuit is incorporated into the system. The manual home/reset circuit utilizes the components and circuits described above for the automatic homing function with the addition of the Manual Home/Reset switch S6. The function of this switch is to artificially interject a logic low transition into the input, pins 1 and 2, of the multivibrator which again, if the Scanivalve is stepping in the automatic mode, will activate the Scanivalve homing and visual indicator reset and hold circuits.

With the system in the automatic mode and in a home and hold state, reactivation of the system is initiated by depressing the Manual Home/Reset switch which alters the output, pin 9, of the flip-flop to logic low with the following results:

1. the Scanivalve homing circuit is activated resulting in the pressure port zero being advanced to the collector port;
2. power, +5 v V_{CC}, is connected to the second 4-bit binary counter, N7493, of the timing circuit, thus enabling the Scanivalve advance circuit;
3. the reset to the indicator circuit and decade counters is set to logic low, thus enabling these circuits.

The end result, then, is that the Scanivalve and the position indicator will again advance in a sequential manner as previously described with termination initiated by coincidence of the thumb-wheel switches and the visual indicators.

VIII. MANUAL SCANIVALVE CONTROL CIRCUIT

As indicated in the Definition of Design (Sec. III), one of the desired control network capabilities is manual control wherein the Scanivalve advance is manually controlled and implemented and the raw data automatically collected from the pressure transducer and processed through the incorporated computer. This design feature is incorporated in the pressure acquisition system through the use of the following:

1. Automatic/Manual switch S1;
2. Manual Step Input switch S4;
3. a one-shot multivibrator;
4. Manual Homing/Reset Circuit;
5. Scanivalve advance control circuit.

The manual Scanivalve advance mode is initiated by placing the Automatic/Manual input switch in the Manual position. This disconnects the automatic timing circuit output from the NAND gate buffer,9002 card 1 (note wiring diagram Fig. 6 and Manual Advance Logic diagram Fig. 11),and connects the output from the manual one-shot multivibrator to the same 9002. Further, to insure compatibility of the Scanivalve pressure port position and the visual position indicator LED's, the Manual Home/Reset switch S6 must be depressed to reset the system and indicators to zero. With these actions accomplished, the system is activated in the manual mode of operation.

With the system at the zero pressure port, the Scanivalve may be advanced to pressure port no. 1 and subsequent sequential ports by depressing the Manual Advance switch S4. The function of this switch is to interject a logic low signal into the input, pins 1 and 2,of the manual one-shot multivibrator, Signetics monolithic TTL type N74122 the operation of which is discussed in the Homing Circuit discussion (Sec. VII). With external timing components similar to the "home" multivibrator, a positive square wave with a variable pulse width (range 0-1.2 seconds) is generated upon depressing S4. The output of the multivibrator is sent to the Automatic/ Manual switch S4 through which it is routed to the decade counters/visual display circuit, previously discussed, and to the Scanivalve advance control circuit.

The Comparator Circuit (Sec. VI) is activated in the manual mode of operation and hence will generate an automatic homing sequence when the visual indicator/decade counter circuit BCD character output coincides with the thumb-wheel output. Likewise, the system must be reactivated by depressing the Manual Home/Reset switch S6.

IX. TRANSDUCER SIGNAL CONDITIONING CIRCUIT

The pressure transducer utilized in the data acquisition system is the Statham bi-stable differential pressure transducer model PM131TC ± 2.5-350 with a scale factor of 1611 micro-volts per volt per psid (note Table III for complete operating specifications). With a 5 volt excitation voltage this scale factor generates 8055 micro-volts per psid, or a transducer output range of ± 20.14 milli-volts.

This pressure transducer utilizes an unbonded Wheatstone bridge sensing circuit. To balance this bridge circuit under a zero psid condition, a 0-50 Kohm variable resistor is mounted on the face of the instrumentation and control panel (note location Fig. 2). Further, to reduce the bridge balance sensitivity, padding resistors (51.5 Kohms) are utilized on either side of the bridge balance resistor as indicated in Fig. 12.

The output from the pressure transducer is routed to a Burr-Brown variable gain operational amplifier. The feedback circuit, illustrated in Fig. 12, provides a variable amplification factor ranging from 285-427, assuming an input impedence of 351 ohms (which is the output impedence of the Statham pressure transducer). Through this combination of pressure transducer and operational amplifier, full scale output range of ± 8.608 volts is realized. Additionally, as noted in Fig. 12, a 0.1 micro-farad filter capacitor is connected in parallel with the feed-back resistors. The function

of this filter capacitor is to reduce the high frequency noise which severely degrades the performance of low voltage analog devices. With this filter capacitor, the noise level is reduced to a tolerable 0.9 milli-volts RMS.

The output from the operational amplifier is routed to the DATEL DM-100 DPM where the analog-to-digital conversion is accomplished. Complete discussion of the conversion process and subsequent signal conditioning is provided in Ref. 2 and Ref. 7.

X. CONCLUSION

The design of a logic control unit and transducer signal conditioning unit allowing the interface of a pressure multiplexing system with an existing multi-purpose digitizing and data logging system has been described in the preceding discussion. The design has been made consistant with the goals of manual and automatic pressure data acquisition at variable Scanivalve stepping speeds over a preselectable maximum pressure port range of 0-47.

The only remaining items to be incorporated in the system are the power supplies (+ 0.6v, + 5v, and ± 15v), which are currently provided by external units. Additionally, a sample check of data flow under an experimental test environment must be made. The software programming for the processing of the digitized data is left to development by the system user since pre-packaged programs exist in the IBM-360/67 SSP library which may be implemented and tailored for specific applications.

It is further concluded that the utilization of the punch-paper tape option of the ASR-33 TTY I/O device will provide an effective and efficient data transfer medium upon incorporation of the Wang 706 interface (ASR-33 to Wang 700). When this equipment becomes available, rapid data acquisition and data reduction into pressure coefficient form will become a reality in the Department of Aeronautics.

Table I

Scanivalve, 48J4-1200, Specifications

1. Temperature: 0° to $80^{\circ}C$

2. Pressure: 0.01 to 500 psid

3. Design: rotary shear plates surfaced with electrolytic sapphire

4. Tubulation: 0.063 inch O.D. standard. All 1 inch extensions are made with staggered lengths.

5. Stepping speed: variable 0 to 20 steps per second

6. Automatic homing speed: 48 steps in two seconds

Table II

Solenoid Controller, CTLR S2-S6, Specifications

1. Unit size: 4.5 x 6.25 x 5.75 inches

2. Power requirements: 115 V.A.C. 50-400 Hz

3. Maximum stepping speed (at "low" power setting): 20 steps per second

4. Commands: remote contact closures, transistor (PNP) switches, manual push buttons for "step" and "home"

5. Command input: command 5 millisecond minimum
recovery 5 millisecond minimum

Table III

Statham Differential Pressure Transducer Specifications

1. Type: PM131TC $\pm$ 2.5-350
2. Pressure range: $\pm$ 2.5 psid
3. Maximum pressure: $\pm$ 5.0 psid
4. Natural frequency: 3500 Hz
5. Positive pressure media: fluids compatible with stainless steel
6. Reference pressure media: dry, non-corrosive gases
7. Internal case pressure: 1 to 65 psia
8. Transduction: resistive balance fully active strain gage bridge
9. Nominal bridge resistance: 351 ohms
10. Excitation: 5 VDC or AC (RMS) through carrier frequencies
11. Full-scale output (open circuit): $\pm$ 4.0 mV/V nominal
12. Resolution: infinitesimal
13. Temperature range: -65 to 250°F
14. Thermal sensitivity shift: less than 0.01%/$^{\circ}$F over temperature range
15. Calibration Factor: 1611 microvolts per volt per psid

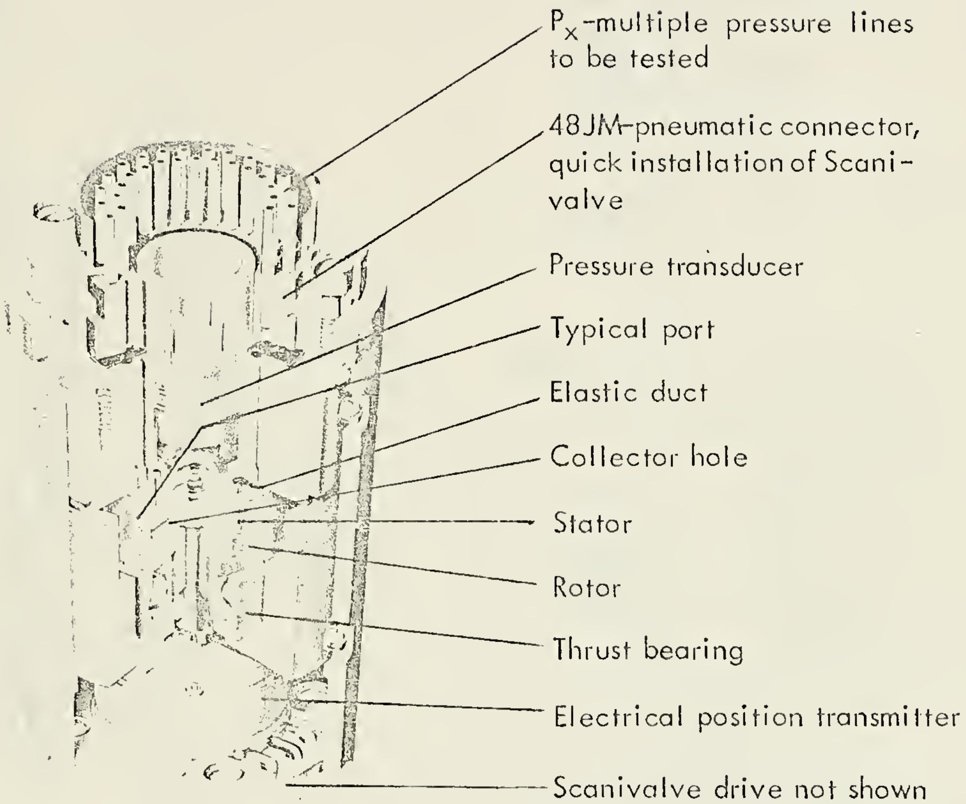


Fig. 1 Cutaway View of Scanivalve

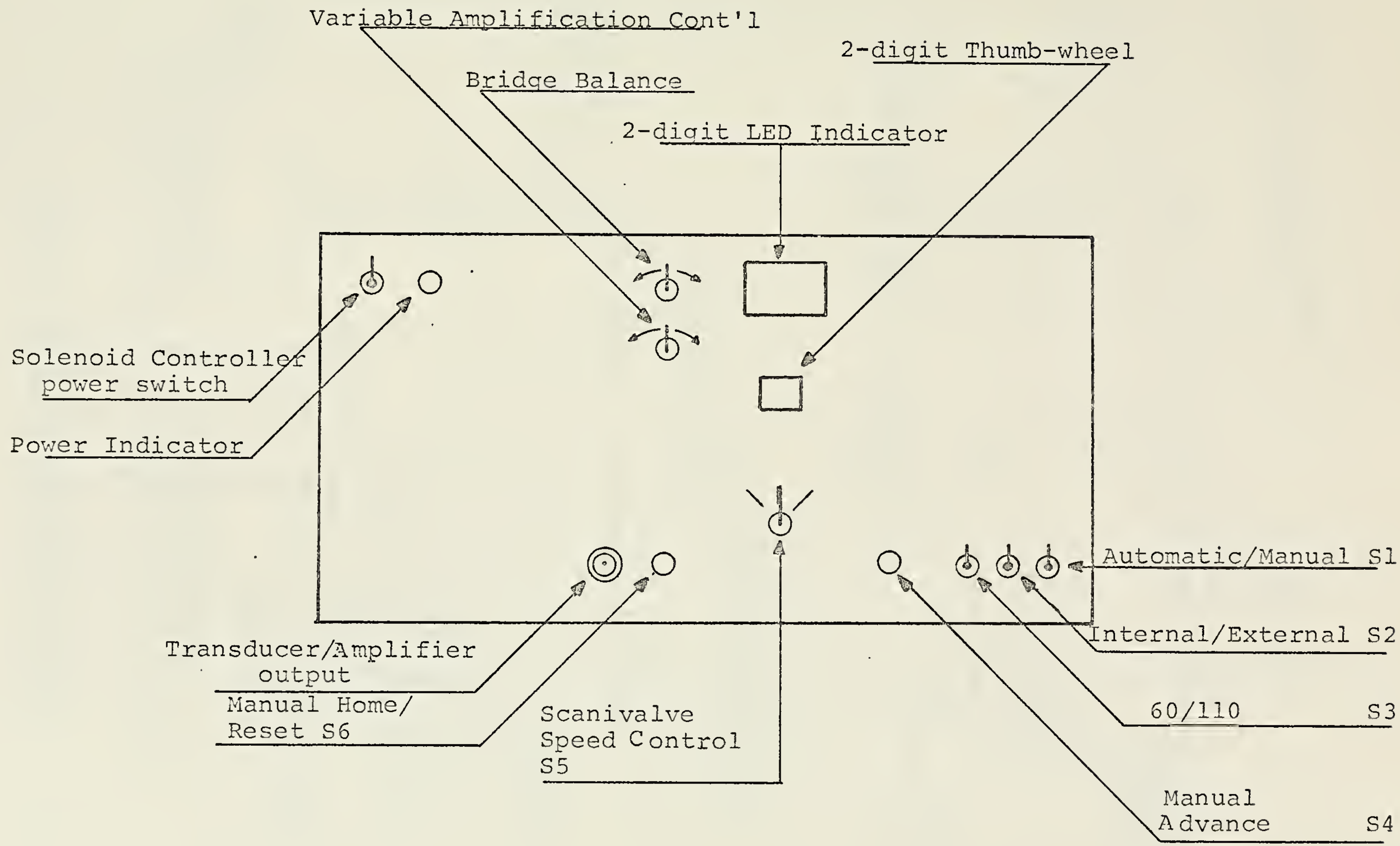


Fig. 2 Front of Instrumentation and Control Panel

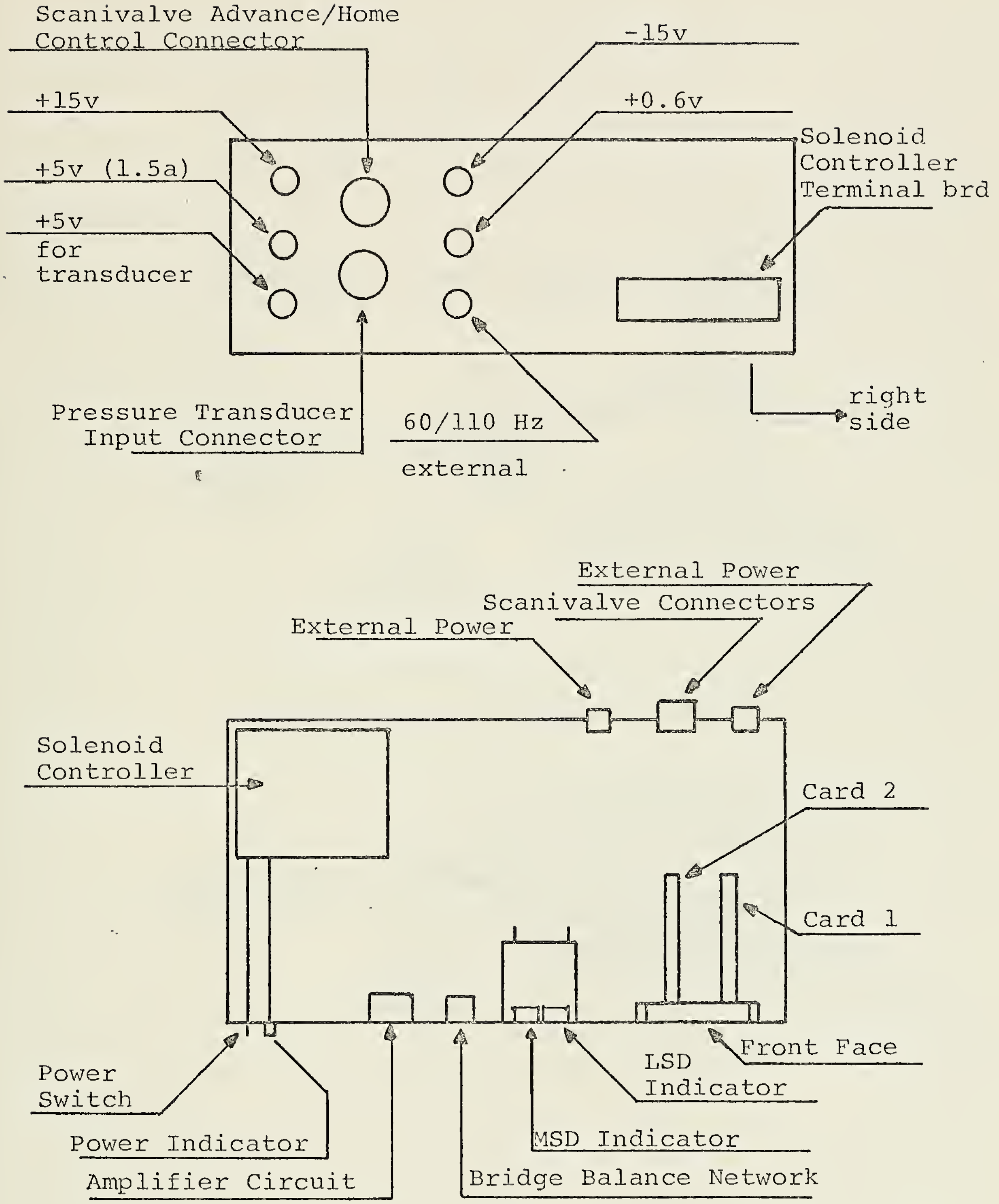
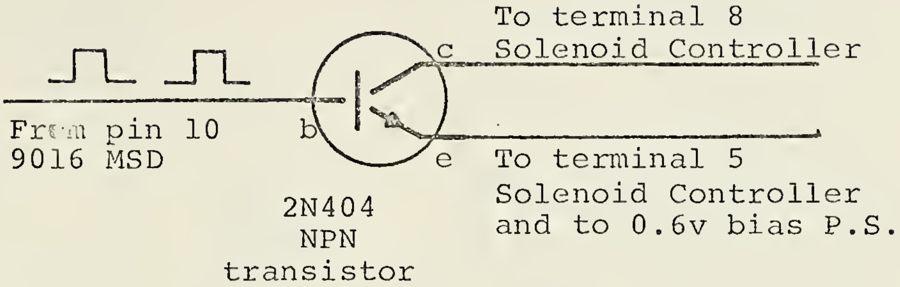


Fig. 3 Top View and Rear View of
Instrumentation and Control Panel

Scanivalve advance transistor circuit



Scanivalve home transistor circuit

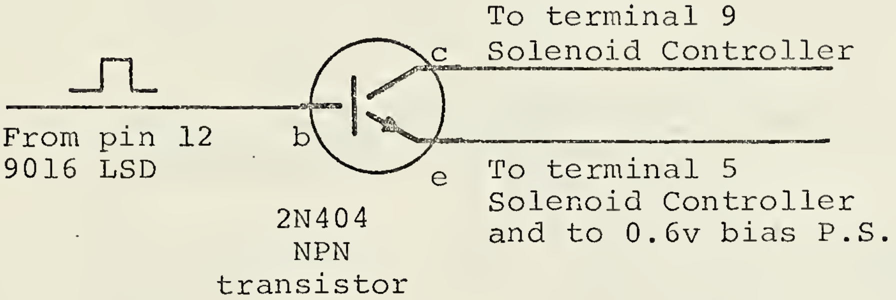


Fig. 4 Transistor Switching Circuit

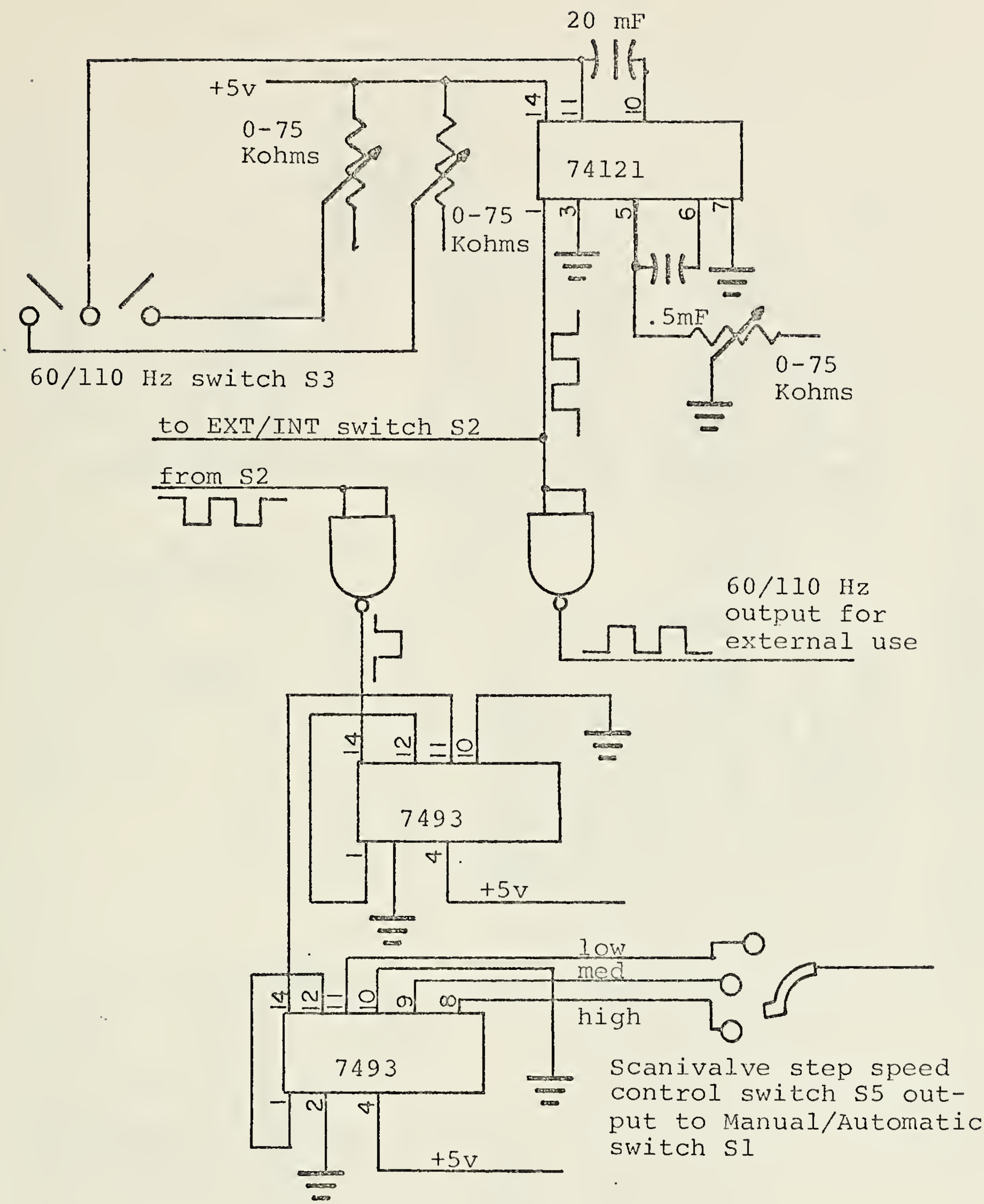


Fig. 5 Timing Circuit Logic Diagram

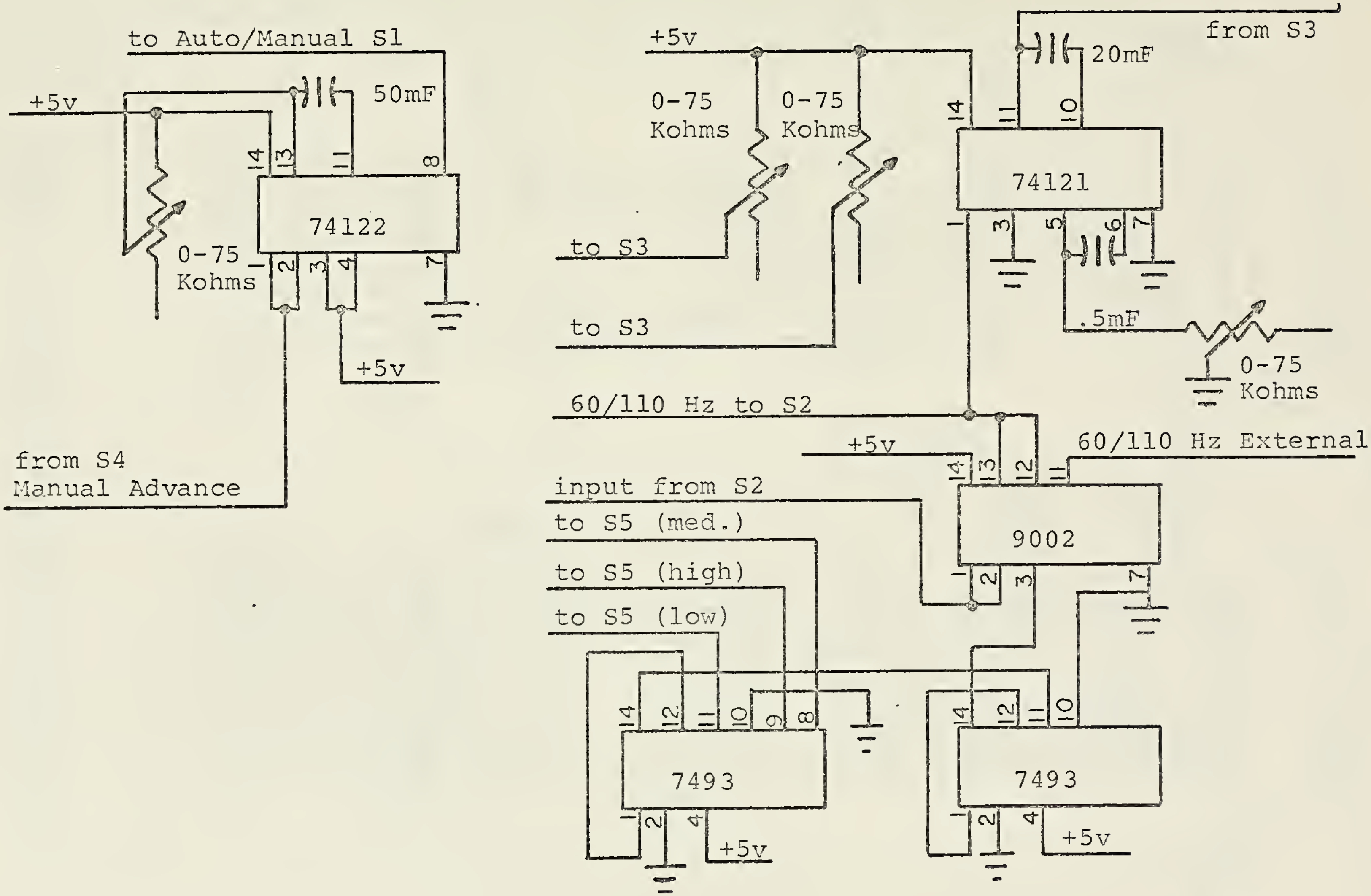


Fig. 6 Wiring Diagram Card 1

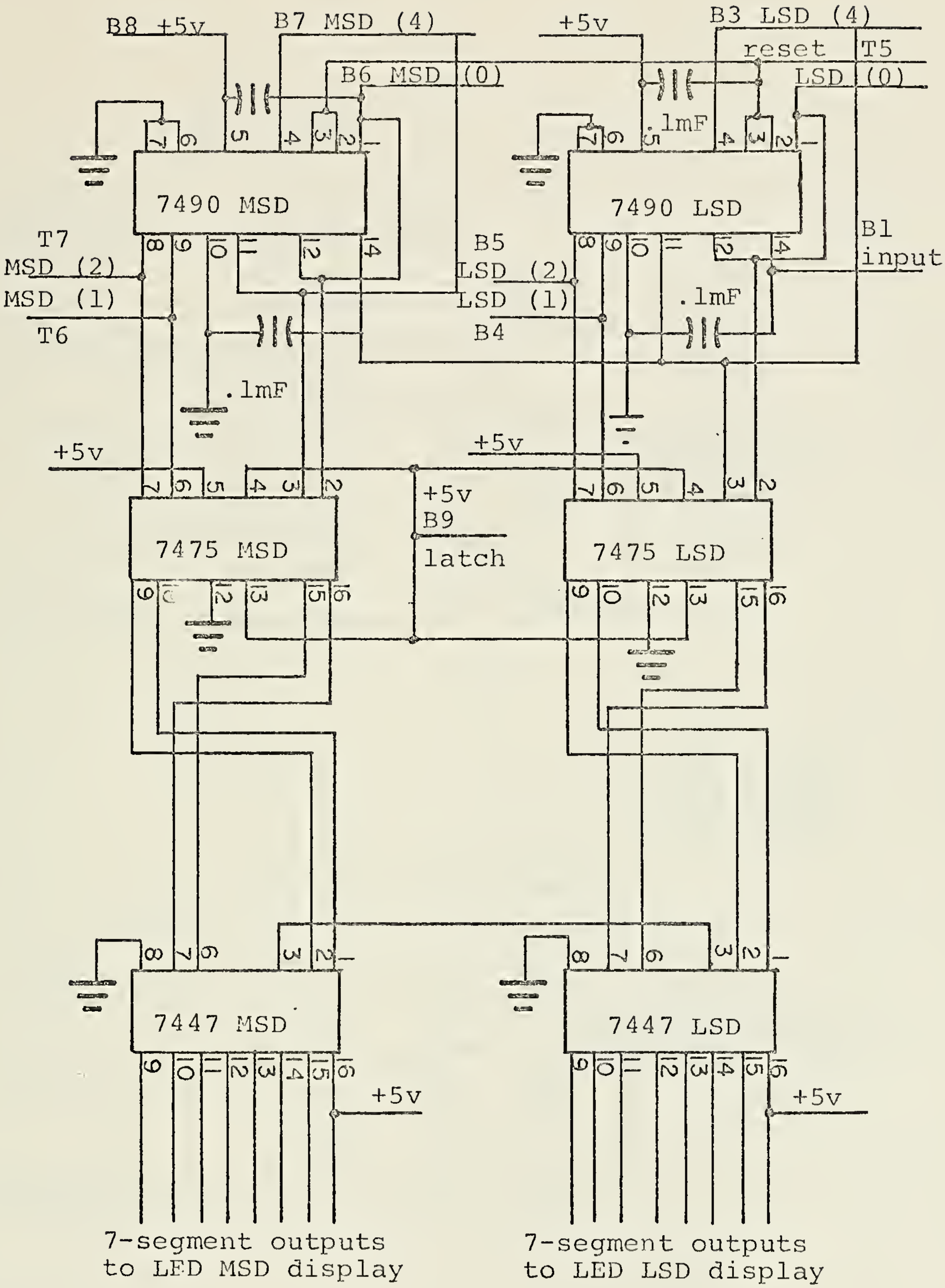


Fig. 7 Position Indicator Wiring Diagram

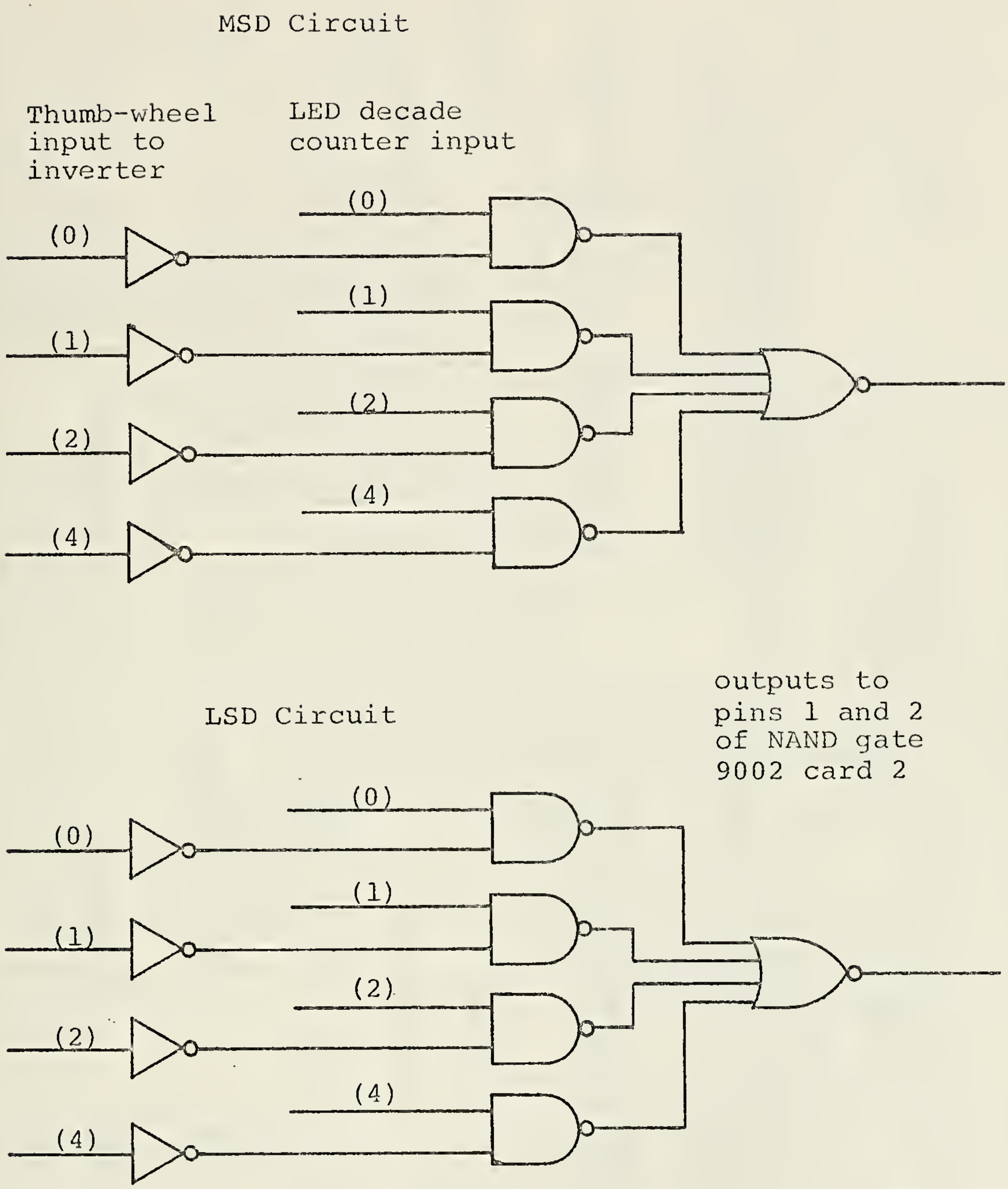


Fig. 8 Logic Diagram of Comparator Circuit

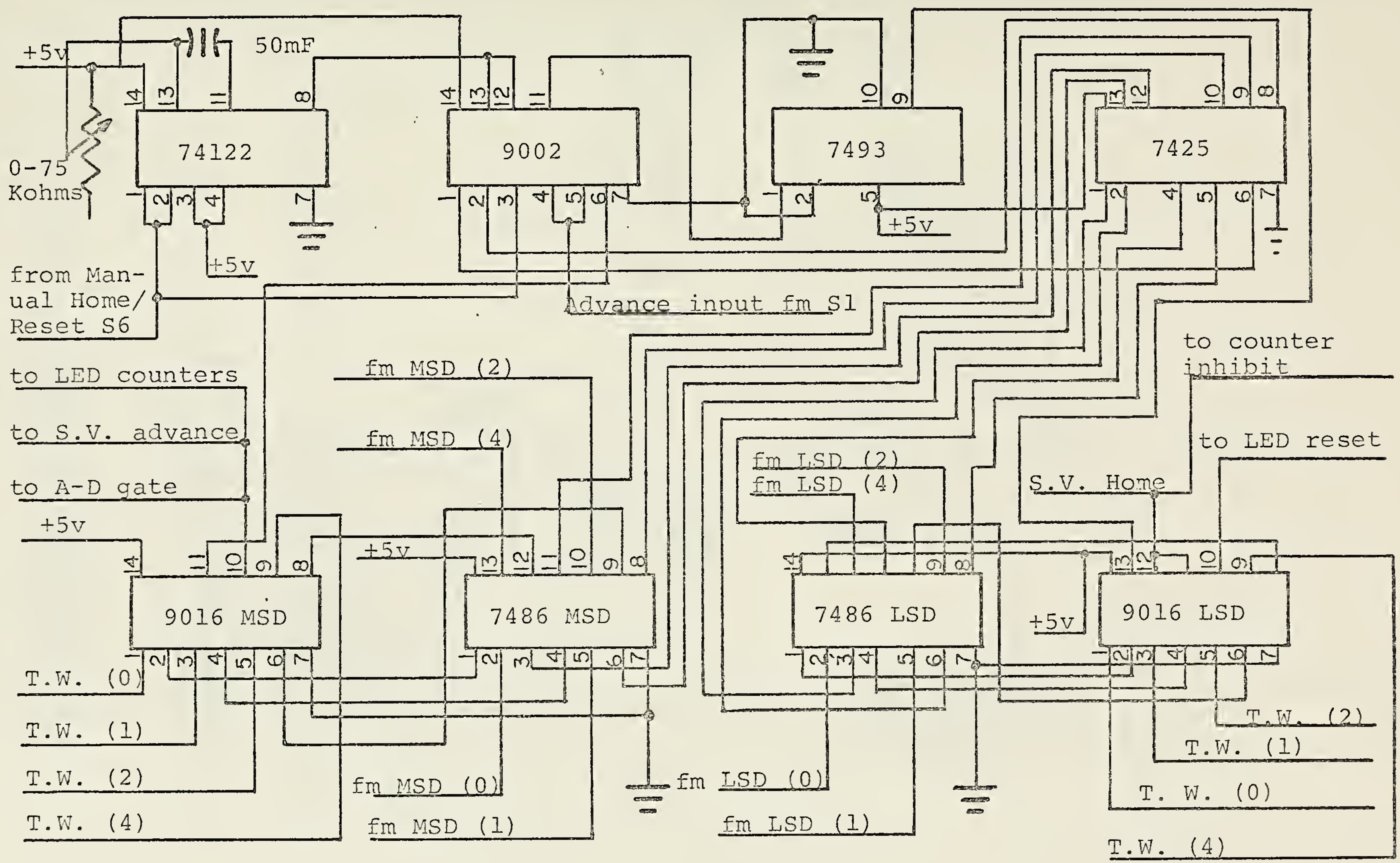


Fig. 9 Wiring Diagram Card 2

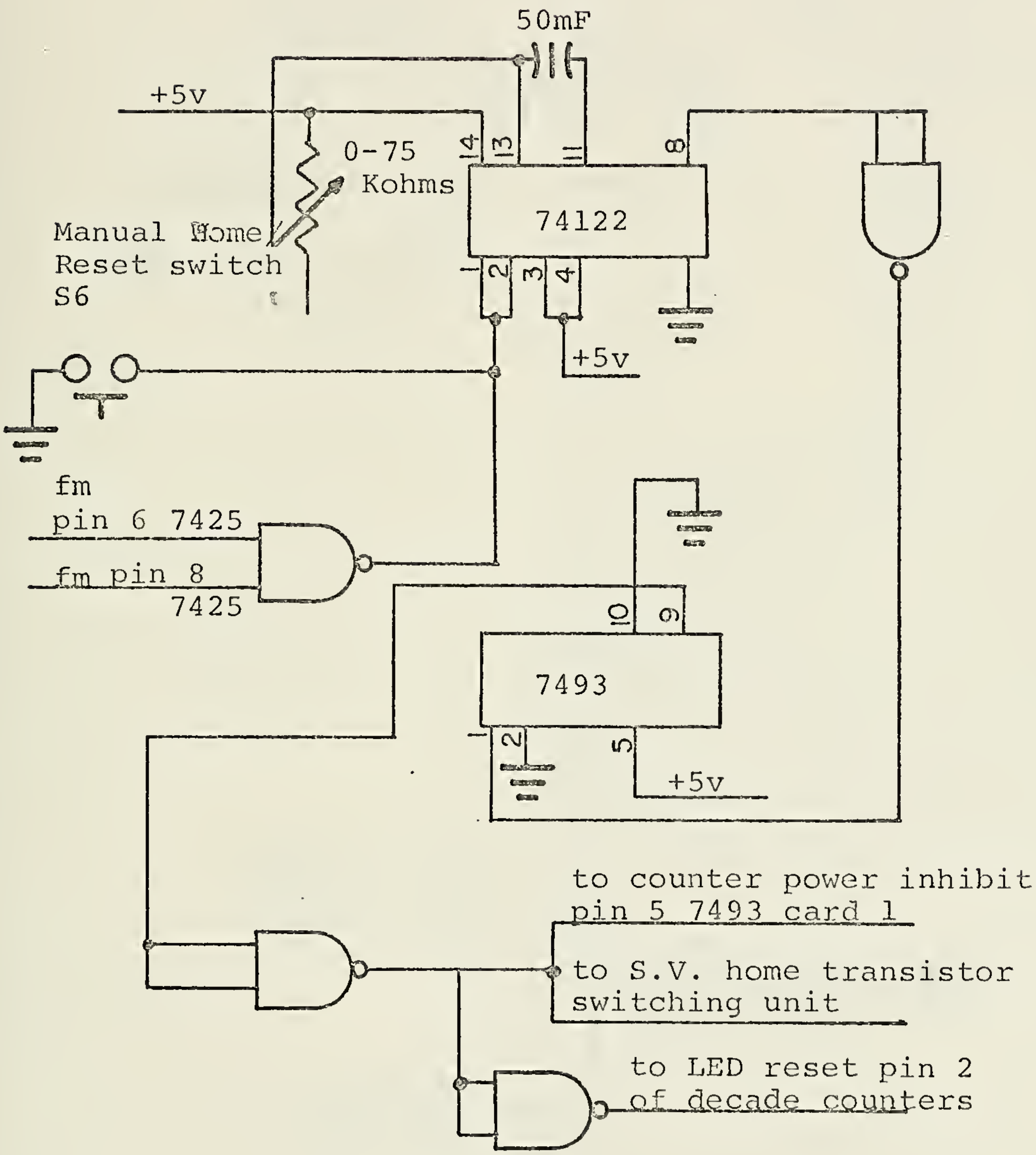


Fig. 10 Automatic/Manual Home and Reset Logic Diagram

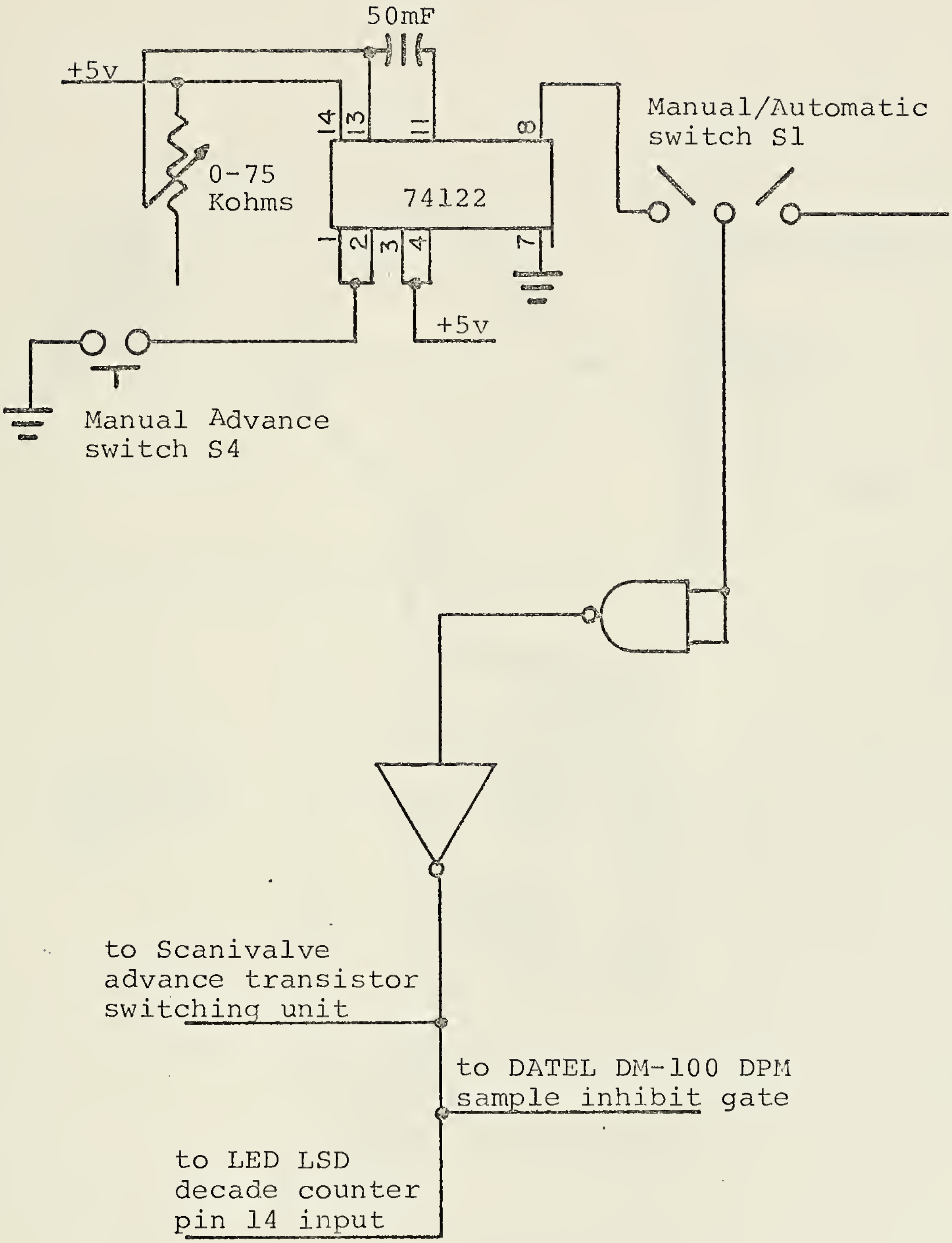


Fig. 11 Manual Advance Logic Diagram

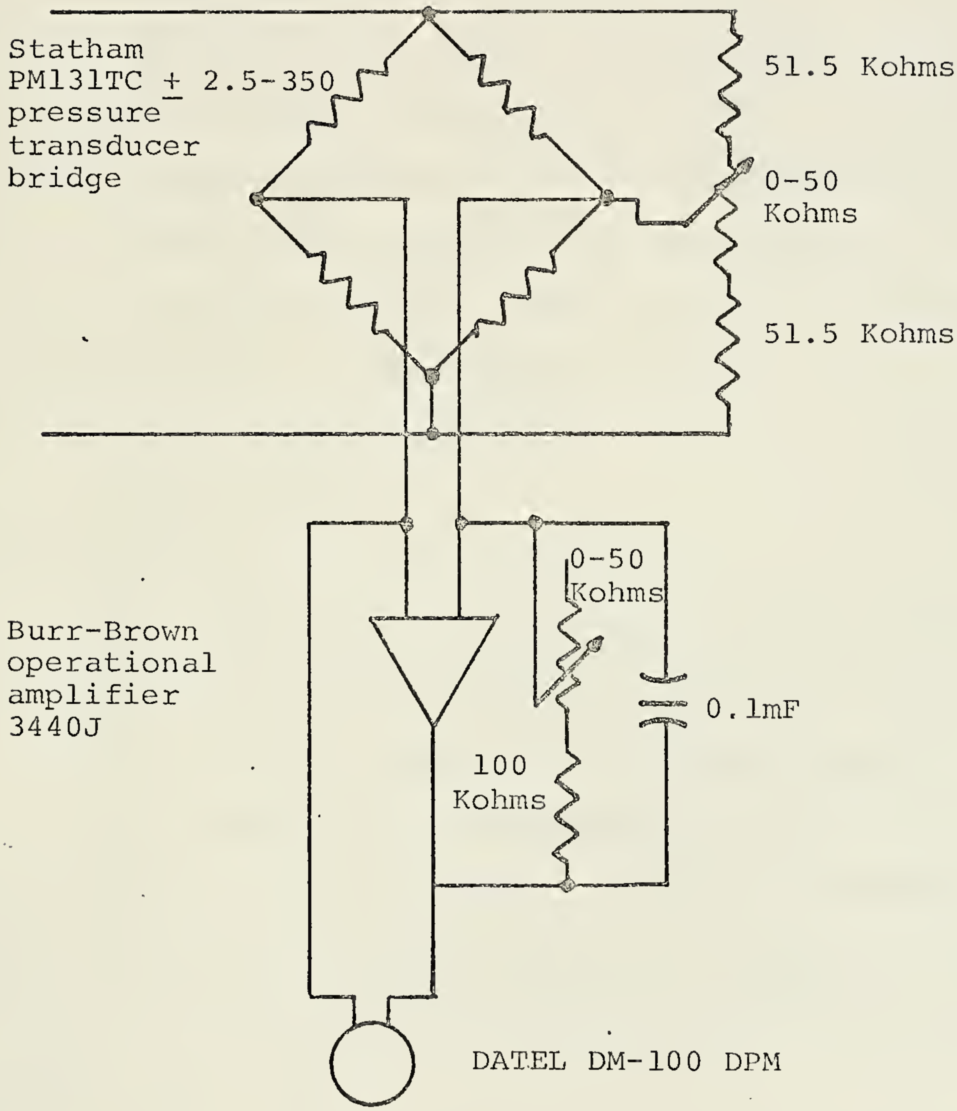


Fig. 12 Logic Diagram of Transducer Bridge and Amplifier

APPENDIX A

ANALOG-TO-ASCII CONTROL BOARD

In numerous experimental evolutions raw data is acquired in the form of an analog signal. This analog signal, after appropriate conditioning, is frequently converted to a digital format compatible with computer input/output (I/O) devices to facilitate automatic data processing (ADP). In the data acquisition system proposed in Ref. 2 and in this thesis research, the input analog signal is to be converted to three-digit-plus-sign ASCII format. Additionally, it is desired to present the data in the following format:

1. ten (10) numbers per line;
2. carriage return;
3. line feed;
4. X off (The X off is an automatic "stop read" character which will cause the tape reader on the ASR-33 TTY to stop and wait for an external command (e.g., from a computer) before resuming the read function.).

Realization of this conversion process is accomplished through utilization of the appropriate integrated circuits delineated in Ref. 2. These circuits, when properly command activated, will:

1. input three (3) binary-coded-decimal (BCD) digits plus sign, and

2. output in ASCII code:

   a. a space;

   b. the appropriate sign;

   c. the corresponding three (3) digit number;

   d. a carriage return;

   e. a line feed;

   f. an X-OFF.

Additionally, these circuits provide functions:

1. a "BUSY" signal to indicate the execution of the translation process and thus to inhibit any disturbing activity;
2. "HALT" if no analog data is ready for conversion;
3. a data-block-header position to facilitate data block identification.

To provide the functional characteristics described above, the circuit illustrated in Fig. 13 was fabricated utilizing commercially available monolithic TTL integrated circuits. Additionally, a DATEL DM-100 Digital Panel Meter (DPM) was utilized as an analog-to-digital converter providing a BCD output over a range of $\pm$ 1.999v with a maximum conversion rate of 1000/sec. This conversion rate limitation does not constitute a serious problem, since the upper limit on any anticipated conversion rate requirement is approximately 80/sec.

The analog-to-ASCII conversion is initiated by bringing pin 10 ("analog data ready") on the Double D Flip-Flop, device 7474, to a logic low state. This takes pin 9 of the

7474 low which starts the DPM's conversion process, and increments the "word counter", device 9316 (a 4-bit binary counter). Upon completion of the analog-to-BCD conversion (about 1.0 milliseconds), the DPM outputs a logic low signal to the reset of the clock control flip-flop, pin 1 of the 7474, thereby enabling the clock which in turn resets the "analog data ready", pin 13 of the 7474. With the clock enabled, the character bit counter is started as well as the transistor board clock. On the first clock pulse, the translator board is activated to read the three-BCD-digit plus sign output from the DPM (NAND gate output labelled parallel-enable (PE)). The character counter, device 7493, is clocked by the eight clock pulse which increments the character count. The MPX outputs select which character from the DPM is being outputted by the translator board. The translator, however, must receive a PE signal before its character count will change. Device 9316, the word counter, allows the character counter to reset on each word except the tenth word in that line. On the tenth word, the word counter suppresses the character counter's attempt to reset counts 5 and 7, providing resets only after a line-feed, carriage-return, X-OFF sequence. The "block head" switch, when closed, causes the word counter to preset to word nine. The next analog data ready signal will then cause a word to be written followed by the normal tenth word sequence of line-feed etc. Additionally, the output "busy out" may be used to prevent a "analog data ready" signal from utilizing external circuitry.

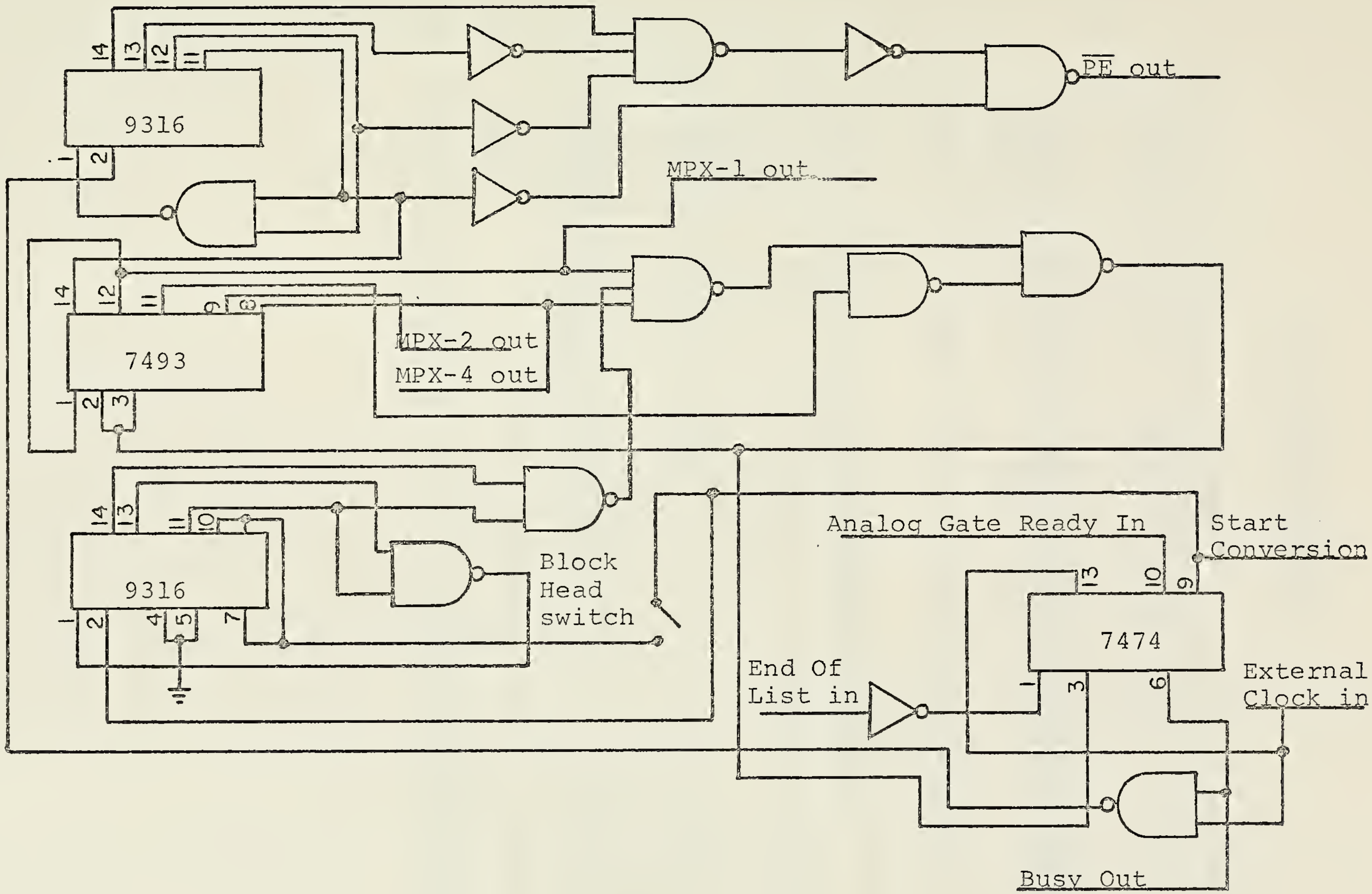


Fig. 13 Analog-To-ASCII Control Board

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A logic interface was designed and fabricated for use between an existing 48-tube pressure multiplexing "Scanivalve" and an ASR-33 Teletypewriter set. The teletype has a punched paper output option, thus allowing rapid data reduction of the digitized data to dimensionless pressure coefficient form utilizing existing computer facilities such as the IBM-360/67, Wang-700, etc. The purpose of the research studies was to

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upgrade the data acquisition facilities and procedures employed in wind-tunnel experimentation in the Department of Aeronautics. Additionally, this work forms a portion of the overall data acquisition problem including the data logging on the wind-tunnel three-component balance.

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W373 Weinzapfel
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the Scanivalve pressure
acquisition device and
the ASR-33 teletypewriter
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